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PATENT APPLICATION TRANSMITTAL LETTER

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TO THE ASSISTANT COMMISSIONER FOR PATENTS:

Transmitted herewith for filing is the patent application of
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(Inventor)

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For -----METHODS AND APPARATUS FOR MODEL BASED SHROUDED BELLOWS STIFFNESS DETERMINATIONS-----

(Title of Invention)

Enclosed are:

☒ 3 sheets of ☐ formal ☒ informal drawing. ☐ Please file concurrently with

☐ an assignment of the invention to **GENERAL ELECTRIC COMPANY**

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GEAE (12/99)

METHODS AND APPARATUS FOR MODEL BASED SHROUDED BELLOWS STIFFNESS DETERMINATIONS

BACKGROUND OF THE INVENTION

This invention relates generally to shrouded bellows and, more particularly, to modeling techniques used to predict natural frequency responses in tube systems that include shrouded bellows.

Shrouded bellows or sealed ball joints are often used in gas turbine engine ducting systems to connect adjacent sections of fluid carrying tubing which require articulation therebetween. The shrouded bellows provide a flexible joint that prevents leakage of the fluid flowing therethrough despite potential movement between the adjacent sections of tubing. Such movement can be for example, caused as a result of thermal growth in the ducting system during engine operation.

Shrouded bellows are typically located in various locations within and around the engine. To design shrouded bellows and associated hardware to withstand High Cycle Fatigue (HCF) stresses, modeling techniques are used to predict natural frequency responses in the ducting systems including the shrouded bellows components. Known modeling techniques use analytical models that approximate shrouded bellows natural frequency response with manufacturer-supplied test data. Such test data is typically obtained from static stiffness component testing. The analytical models incorporate static stiffness data by assigning a spring constant to various spring elements used to represent the shrouded bellows within the analytical models. The spring elements provide the bellows stiffness input for an analytical determination of the system natural frequency response. Because the shrouded bellows natural frequency response is based on static stiffness test data, the ability of the analytical models to accurately estimate the natural frequency response of shrouded bellows is potentially limited.

EXPRESS # EL627655330US - AUGUST 31, 2000

BRIEF SUMMARY OF THE INVENTION

In an exemplary embodiment, a modeling system accurately predicts natural frequency responses in tube sub-systems that include shrouded bellows components. The modeling system characterizes the shrouded bellows using a standard geometry element that includes an assigned stiffness multiplier based on dynamic stiffness component data rather than static stiffness component test data. In the exemplary embodiment, the modeling system characterizes the shrouded bellows using a standard geometry element that is a tube element that includes an applied flexibility factor, and the modeling system determines the flexibility factor using regression techniques. An exemplary regression equation accounts for tube system diameter, bellows pitch, system operating pressure, and dynamic system operating input. The modeling system facilitates accurate predictions of natural frequency responses in tube sub-systems that include shrouded bellows components in a cost effective and reliable manner.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a front schematic illustration of a tube sub-system including a plurality of shrouded bellows;

Figure 2 is a partially cut-away side view of a shrouded bellow used with the tube sub-system shown in Figure 1; and

Figure 3 is a flowchart of a method for modeling natural frequency responses in tube sub-systems such as the tube sub-system shown in Figure 1.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is a front schematic illustration of a tube sub-system 10 including a plurality of shrouded bellows 12. Tube sub-system 10 is attached radially outwardly from a gas turbine engine 14 with a plurality of rod end links 16. Rod end links 16 extend radially outward from an outer surface 20 of an engine casing 22. Each rod end link 16 includes a circular strap 24 for securing to tube sub-system 10.

Tube sub-system 10 includes a plurality of tubing sections 30 connected together to form a flow passageway. Each rod link strap 24 secures to one of tubing sections 30 and secures such tubing section 30 to engine casing 22. Each shrouded bellow 12, described in more detail below, is connected in flow communication between adjacent tubing sections 30 and provides a flexible joint that has substantially leak-proof angulation between adjacent sections of tubing 30. Furthermore, bellows 12 provide flexibility for tube sub-system 10 which may be required in order to physically deflect tubing sections 30 so as to improve installation ease with other components (not shown) of engine 14 and to accommodate thermal growth of tubing sections 30 during engine operation.

Figure 2 is a partially cut-away side view of shrouded bellows 12 used to join a first tube 34 in flow communication with a second tube 36. Shrouded bellows 12 prevents leakage of fluid between adjacent tubes 34 and 36 while providing pivotal or articulated movement between tubes 34 and 36. First tube 34 has a first diameter 37 and second tube 36 has a second diameter 38.

Shrouded bellow 12 includes a tubular outer shroud 40 which surrounds in part a coaxial tubular inner shroud 42. Outer shroud 40 is one piece and includes at a first end 44, an integral cylindrical sleeve 46 for attaching to first tube 34. Shroud 40 also includes at a second end 48, an integral spherical concave annulus 50.

Inner shroud 42 includes at a first end 52 a cylindrical sleeve 54 for attaching to second tube 36. Shroud 42 includes at a second end 56 an integral spherical convex annulus 58. An outer diameter (not shown) of convex annulus 58 is approximately equal an inner diameter (not shown) of concave annulus 50 such that inner shroud convex annulus 58 is in slidable contact with outer shroud concave annulus 50.

A tubular bellows 74 is coaxial with a center axis of inner and outer shrouds (not shown). Bellows 74 is between inner shroud 42 and a bellows liner 75, permitting first and second pieces of tubing 34 and 36, respectively, to sealingly join

while permitting limited pivotal movement therebetween. Bellows 74 include a plurality of axially spaced apart convolutions 76 that provide a flexible seal between inner and outer shrouds 42 and 40, respectively. Corresponding portions of adjacent convolutions 76 define a pitch 80 for bellows 74.

Figure 3 is a flowchart 100 of a method for modeling natural frequency responses in tube sub-systems, such as tube sub-system 10 (shown in Figure 1), that include shrouded bellows 12 (shown in Figures 1 and 2). The method can be practiced on a computer (not shown), such as a personal computer or a workstation, including an interface (not shown), such as a keyboard and an a display, a processor, and a memory.

Initially, input values are chosen 110 that are indicative of tube sub-system characteristics. More specifically, values for dynamic operating condition inputs 114 and shrouded bellows geometry inputs 116 are selected. In the exemplary embodiment, dynamic operating condition inputs 114 include at least data representing an operating pressure and vibratory environment of tube sub-system 10 (shown in Figures 1 and 2) and shrouded bellows geometry inputs 116 include data representing bellows pitch 80 (shown in Figure 2) and bellows mating tube diameters 37 and 38 (shown in Figure 2). Such inputs 114 and 116 are, for example, selected by an operator.

A stiffness multiplier for tube sub-system 10 being analyzed is then determined 120. Instead of modeling shrouded bellows 12 (shown in Figures 1 and 2) as spring elements including an assigned spring constant that is based on static stiffness component test data, shrouded bellows 12 is characterized using a standard geometry element that includes an assigned stiffness multiplier based on dynamic stiffness component test data. The stiffness multiplier is a finite element input that may be selectively adjusted to customize a dynamic stiffness of a particular shrouded bellows element. The stiffness multiplier is determined 120 with a regression equation that accounts for tube sub-system diameter 37 and 38, system operating pressure, bellows pitch 80, and dynamic system operating inputs.

The regression equation is based on dynamic stiffness test data obtained as a result of testing several different shrouded bellows configurations. Each different shrouded bellows configuration can be analytically modeled to determine a unique stiffness multiplier for that specific shrouded bellows configuration and to generate a tube sub-system analytical model. The stiffness multiplier regression equation may used for a broad range of tube sub-system sizes and operating conditions reflective of the dynamic stiffness test data upon which the modeling was based. Within the tube sub-system analytical model, the appropriate stiffness multiplier is input 124 to the standard geometry bellows element.

In the exemplary embodiment, shrouded bellows 12 are characterized using a standard geometry element that is a tube element that includes a stiffness multiplier that is an applied flexibility factor. The flexibility factors were determined using an iterative scheme that optimized the flexibility factors by matching the natural frequency responses of the tube elements in a finite element analysis to the natural frequency responses of vibratory component tests. The flexibility factors assigned to the standard tube elements were varied incrementally until the analytical natural frequency response of the bellows element equaled the natural frequency response of the bellows test component. For example, in one embodiment, a three inch diameter shrouded bellows centered on a twelve inch cantilevered straight tube section (not shown) within a system pressurized to approximately 100 psia in an approximately constant 2g vibratory environment, produced a natural frequency response of 166 Hz. The test component was modeled using finite element analysis to determine that assigning a flexibility factor of approximately 0.328, enabled the analytical model to yield the same natural frequency response as the component test piece under the approximate same operating conditions.

The tube sub-system analytical model is then solved 130 to determine or predict 132 a tube sub-system natural frequency response. As a result, because more accurate estimates of shrouded bellows dynamic response are facilitated, shrouded bellows tube sub-systems may be designed more reliably.

In one embodiment, tube sub-system is a CF34-8 aircraft engine cooling system (not shown) available from General Electric Aircraft Engines, Cincinnati, Ohio and the tube system natural frequency responses of the CF34-8 aircraft engine cooling system are predicted 132. A regression equation uses vibratory environment inputs 114, operating pressures 114, tube system diameters 37 and 38, and bellows pitch information 80 to determine 120 flexibility factors for bellows elements 12 included in the CF34-8 aircraft engine duct system. The regression equation determines 120 the flexiblity factors to be assigned to tube bellows elements. Solving the finite element analysis provides the natural frequency response of the CF34-8 aircraft engine duct system for a specified engine vibratory environment. The resulting natural frequency response facilitates determining locations for duct supports.

The above-described modeling method is cost-effective and accurate. The modeling method simulates and predicts a stiffness of shrouded bellows through the use of a regression equation. The regression equation, based on dynamic stiffness test data of a plurality of shrouded bellows configurations, permits the shrouded bellows to be characterized using a standard geometry element that includes an assigned stiffness multiplier based on the dynamic stiffness test data. As a result, the modeling method permits predictions of natural frequency responses in tube sub-systems that include shrouded bellows components in a cost effective and reliable manner.

While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.

WHAT IS CLAIMED IS:

1. A method for predicting natural frequency responses in tube sub-systems including shrouded bellows components, said method comprising the steps of:

determining a stiffness multiplier from input values; and

using the determined stiffness multiplier in a model to predict a natural frequency response.

2. A method in accordance with Claim 1 further comprising the step of inputting dynamic system operating inputs into the model.

3. A method in accordance with Claim 2 wherein said step of inputting dynamic system operating inputs further comprises the step of inputting at least an operating pressure and vibratory environment into the model.

4. A method in accordance with Claim 2 further comprising the step of inputting geometry inputs including at least one of a bellows pitch and a mating tube diameter into the model.

5. A method in accordance with Claim 3 wherein said step of determining a stiffness multiplier further comprises the step of using a regression technique to determine the stiffness multiplier.

6. A method in accordance with Claim 3 further comprising the step of determining system stiffness as a function of the stiffness multiplier.

7. A modeling system for determining natural frequency response of shrouded bellows components, said system configured to determine a stiffness multiplier from input values.

8. A modeling system in accordance with Claim 7 wherein the stiffness multiplier is used to determine the natural frequency response.

9. A modeling system in accordance with Claim 8 wherein the input values include at least one of shrouded bellows geometry inputs and dynamic operating condition inputs.

10. A modeling system in accordance with Claim 8 wherein the bellows geometry inputs include at least one of a tube sub-system diameter and a bellows pitch.

11. A modeling system in accordance with Claim 8 wherein the dynamic operating condition inputs include at least an operating pressure.

12. A modeling system in accordance with Claim 8 wherein the stiffness multiplier is adjustable such that a dynamic stiffness of the shrouded bellows is selectively variable.

13. A modeling system in accordance with Claim 8 wherein the stiffness multiplier is determined using a regression technique.

14. A system for determining natural frequency response of shrouded bellows components, said system comprising a model configured to predict the natural frequency response as a function of a stiffness multiplier.

15. A system in accordance with Claim 14 wherein said model further configured to determine the stiffness multiplier from input values

16. A system in accordance with Claim 15 wherein the input values include at least one of shrouded bellows geometry inputs and dynamic operating condition inputs, the shrouded bellows geometry inputs including at least one of a tube sub-system diameter and a bellows pitch, the dynamic operating condition inputs including at least an operating pressure.

17. A system in accordance with Claim 14 wherein the stiffness multiplier is adjustable such that a dynamic stiffness of the shrouded bellows is selectively variable.

18. A system in accordance with Claim 14 wherein the stiffness multiplier determined using a regression technique.

19. A system in accordance with Claim 18 wherein the regression technique comprises a regression equation.

METHODS AND APPARATUS FOR MODEL BASED SHROUDED BELLOWS STIFFNESS DETERMINATIONS

ABSTRACT OF THE DISCLOSURE

A modeling system predicts natural frequency responses in tube sub-systems including shrouded bellows components. The system determines a stiffness multiplier from input values and uses the determined flexibility factor to determine the natural frequency responses. The input values include geometry inputs and dynamic operating condition inputs. The flexibility factor is determined with a regression equation. The regression equation, based on dynamic stiffness test data of various shrouded bellows configurations, permits the system to characterize the shrouded bellows using a geometry element that includes an assigned flexibility factor based on dynamic stiffness test data.

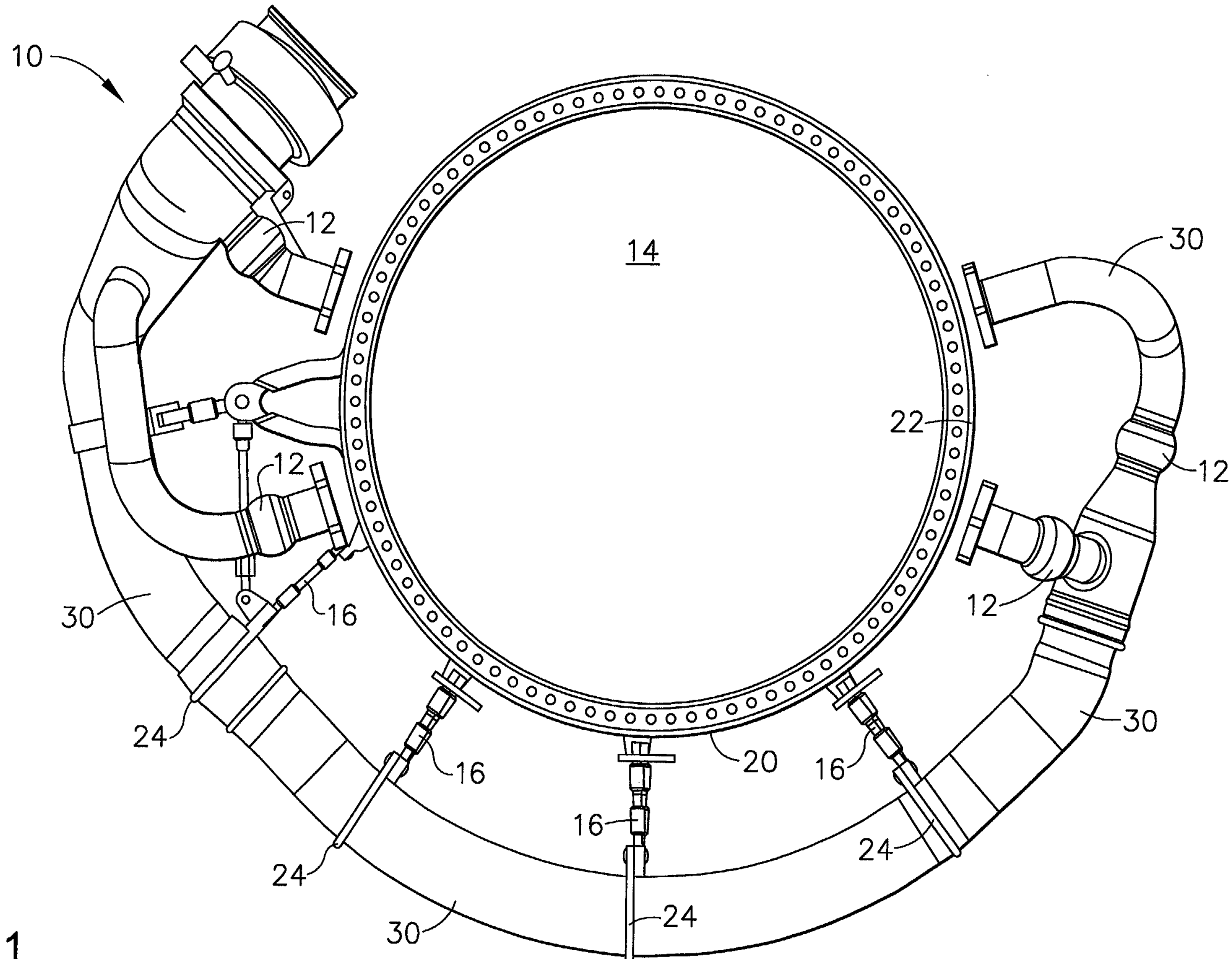

FIG. 1

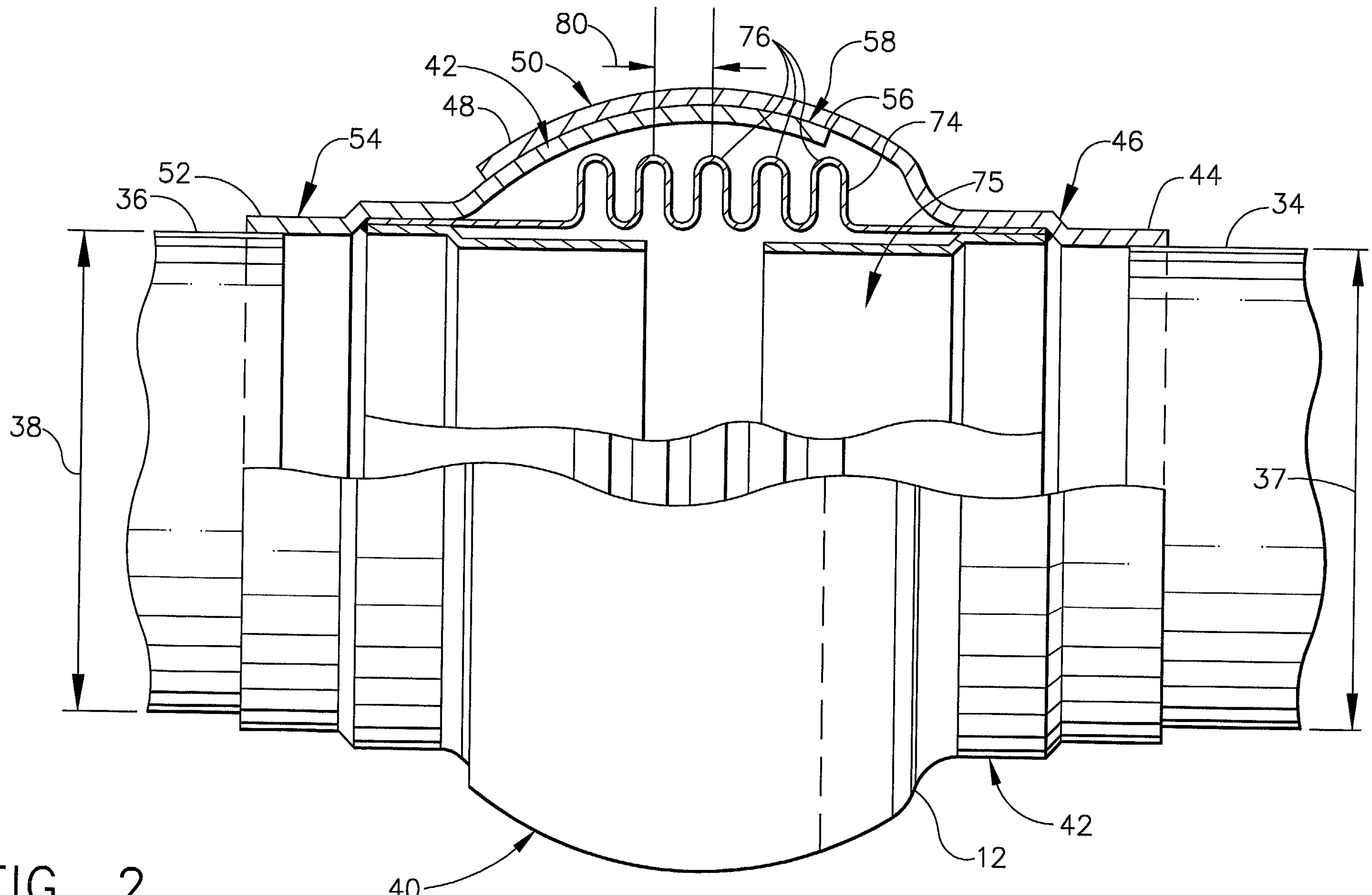

FIG. 2

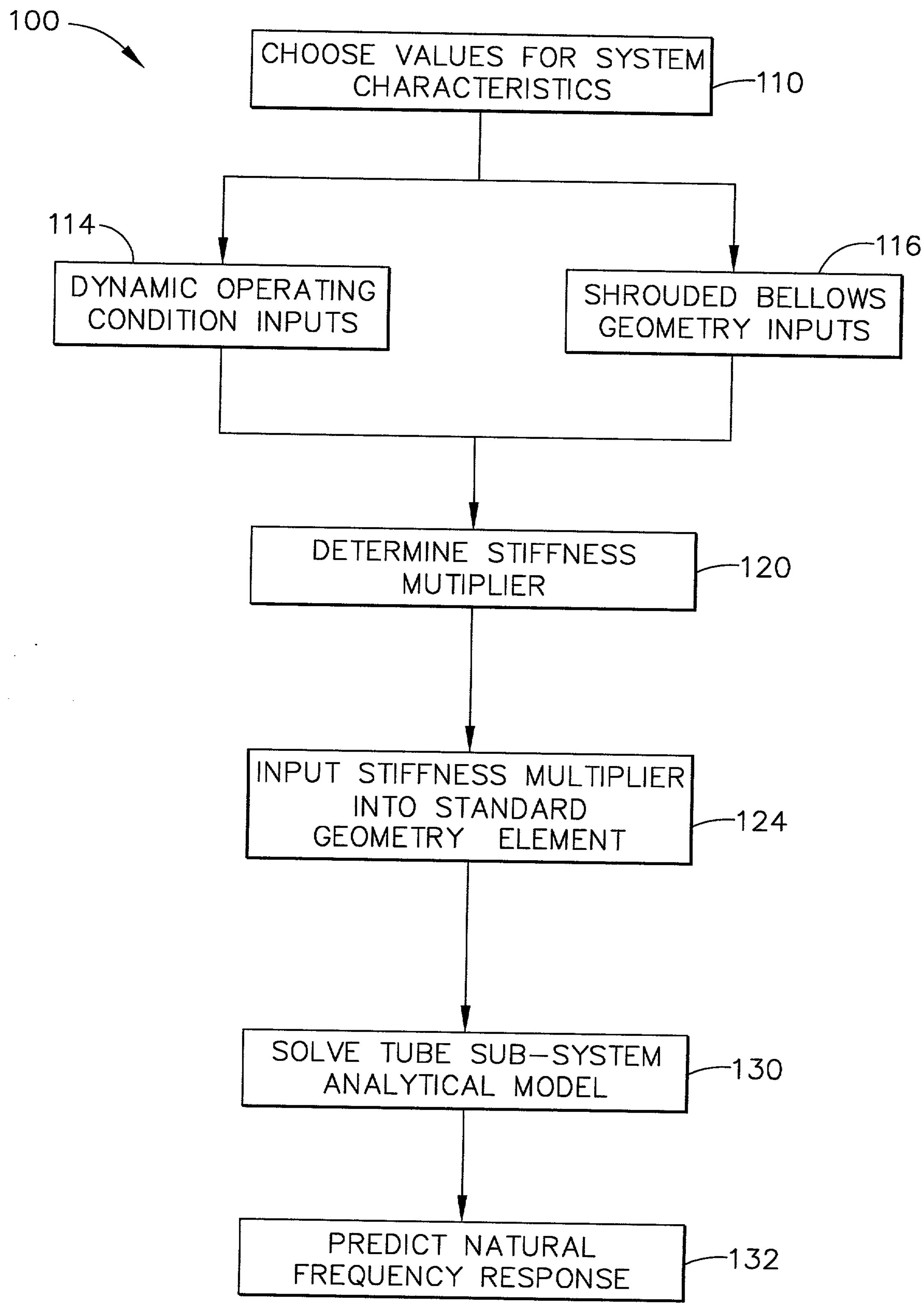
100
CHOOSE VALUES FOR SYSTEM CHARACTERISTICS
110
114
DYNAMIC OPERATING CONDITION INPUTS
116
SHROUDED BELLOWS GEOMETRY INPUTS
DETERMINE STIFFNESS MUTIPLIER
120
INPUT STIFFNESS MULTIPLIER INTO STANDARD GEOMETRY ELEMENT
124
SOLVE TUBE SUB–SYSTEM ANALYTICAL MODEL
130
PREDICT NATURAL FREQUENCY RESPONSE
132

FIG. 3

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

Docket Number
13DV13495

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

-----METHODS AND APPARATUS FOR MODEL BASED SHROUDED BELLOWS STIFFNESS DETERMINATIONS-----

the specification of which

☒ is attached hereto

OR

☐ was filed on ____________ as United States Application Number or PCT International Application Number ____________

and was amended on ____________ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37 Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code §119 (a)-(d) or §365 (b) of any foreign application(s) for patent or inventor's certificate, or §365 (a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

PRIOR FOREIGN APPLICATION(s)

(Number)	(Country)	(Day/Month/Year Filed)	Priority Claimed
			☐ Yes ☐ No
			☐ Yes ☐ No

☐ Additional foreign application numbers are listed on a supplemental priority data sheet attached hereto.

I hereby claim the benefit under Title 35, United States Code §119 (e) of any United States provisional application(s) listed below.

(Application Number)	(Filing Date)

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(Application Number)	(Filing Date)	(Status - patented, pending, abandoned)

I hereby appoint the registered practitioners associated with Customer Number 006111 to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

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